



STEPS: JPL's Astrometric Exoplanet Survey

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**Exoplanet Science Fair
JPL**

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STEPS



STEPS ground-based astrometry at Hale Telescope



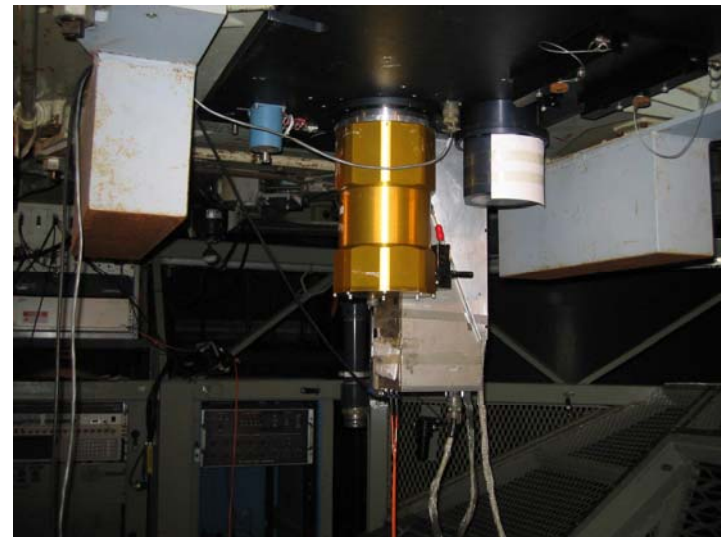
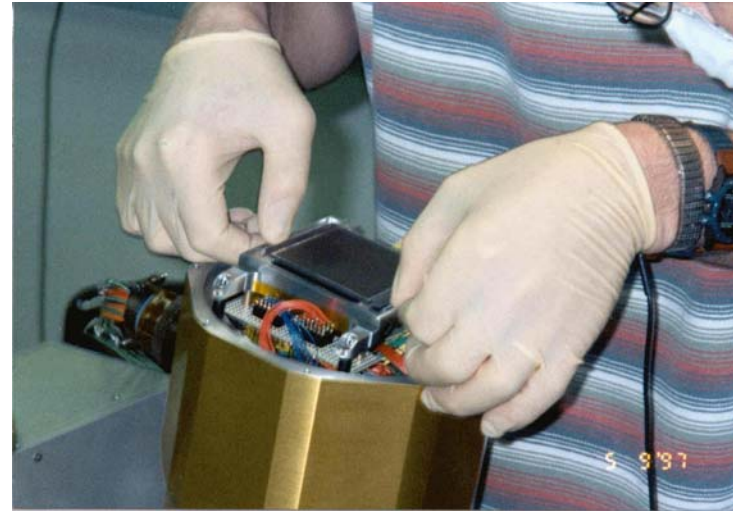
- Started December, 1997. Now in 10th year.
- 30 nearby late M-dwarf stars, $V = 12-16$.
- Search for $> 1 M_J$ planets and brown dwarfs
- 4k x 4k CCD, 2 arcmin field

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- Past and present collaborators: Fritz Benedict (spectroscopy), Michael Endl (RV), James Lloyd (AO), Shri Kulkarni (AO), Todd Henry (HST),
- Discoveries: M-dwarf and Brown Dwarf companions to several M-dwarf stars.



- **4K Loral CCD**
- **LN2 Dewar**
- **SDSU (Leach) Electronics**
 - 4 amplifiers
 - Bin pixels 2x2
 - 200 kpix read rate
- **Binned pixel scale = 78 mas/pix**
- **Bandpass 550 – 750 nm**
- **Mounts at straight-Cass, f/16 on the Palomar 200 in. telescope.**
 - Was also used at Keck II in 1998.
- **Window has high quality $\lambda/30$ p-v wavefront.**
 - Filter glass + dielectric coating
 - Focus term due to vacuum is absorbed by the conformal model.





Why Astrometry? Why M-dwarfs?

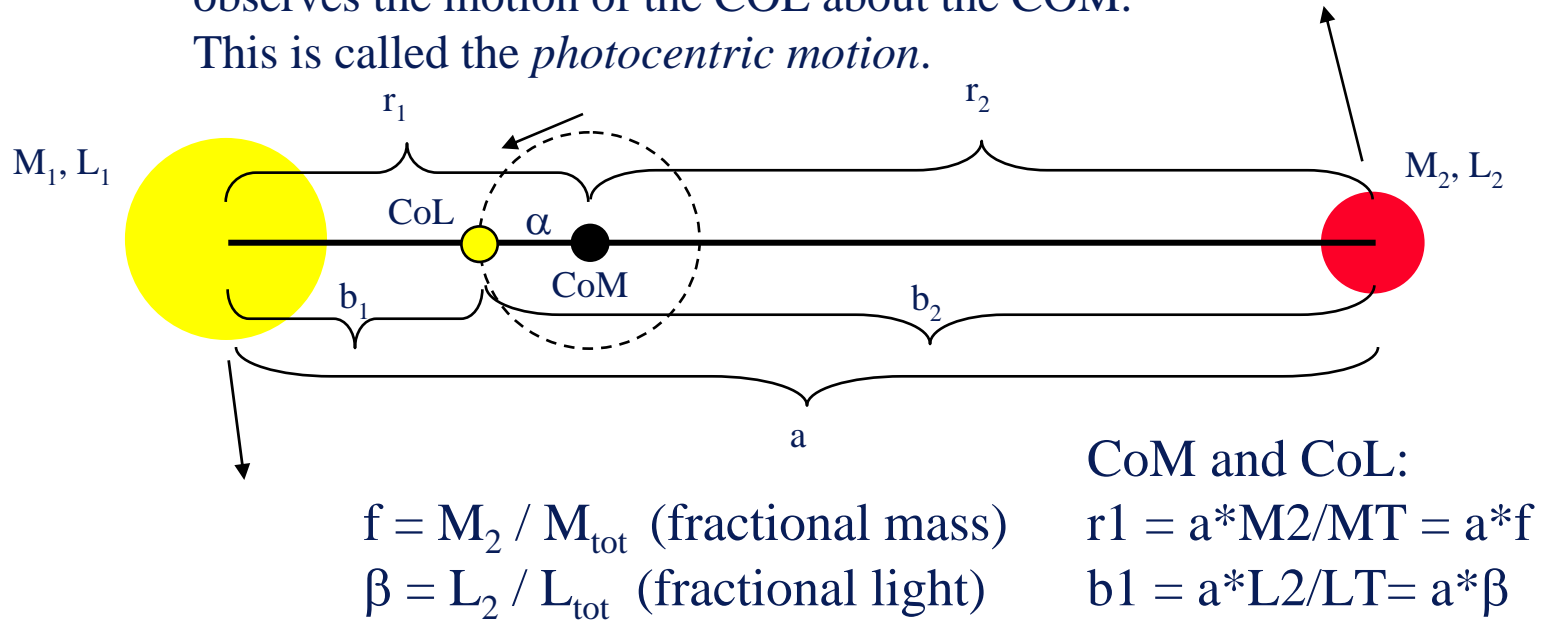


- **M-dwarfs**
 - Most abundant stars: 70%, and least sampled by RV
 - Larger signal for a given planet mass
 - Additional science: Mass-luminosity relationship, finding BD companions
- **Complementary to RV**
 - Astrometry is best at long periods, RV is best at short periods
 - Astrometry improves at redder wavelengths
 - Better seeing, less dispersion
 - RV gets worse at redder wavelengths
 - Fewer, broader lines.
 - Resolves *sini* ambiguity and measures dynamical mass
- **Complimentary Astrometry Programs:**
 - CAPSCAM (A. Boss, Carnegie)
 - Dupont Telescope: better seeing helps compensate smaller telescope
 - High-dynamic range detection: closer targets = larger signal
 - VLBA observations (Geoff Bower) of 30 M-dwarfs
 - 200 uas, 3 yrs, 12 measurements
 - About half are late M-dwarf. Maybe some overlap with STEPS

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Motion of Center of Light about Center of Mass: Photocentric Orbit

For unresolved systems (< 1 arcsec separation), STEPS observes the motion of the COL about the COM.
This is called the *photocentric motion*.



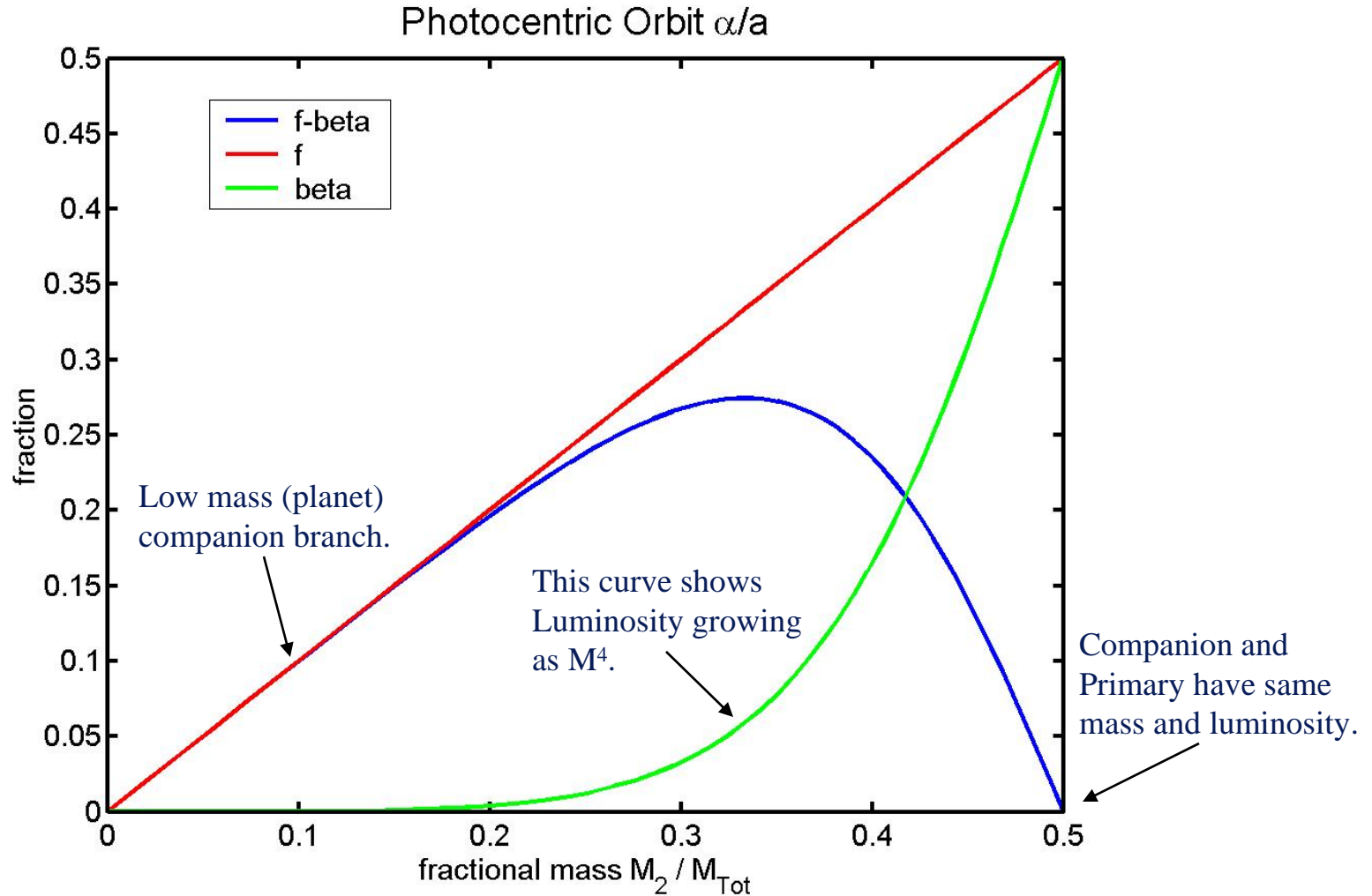
STEPS Measures:

$$\alpha = \text{CoL} - \text{CoM} = r_1 - b_1 = a * (f - \beta)$$

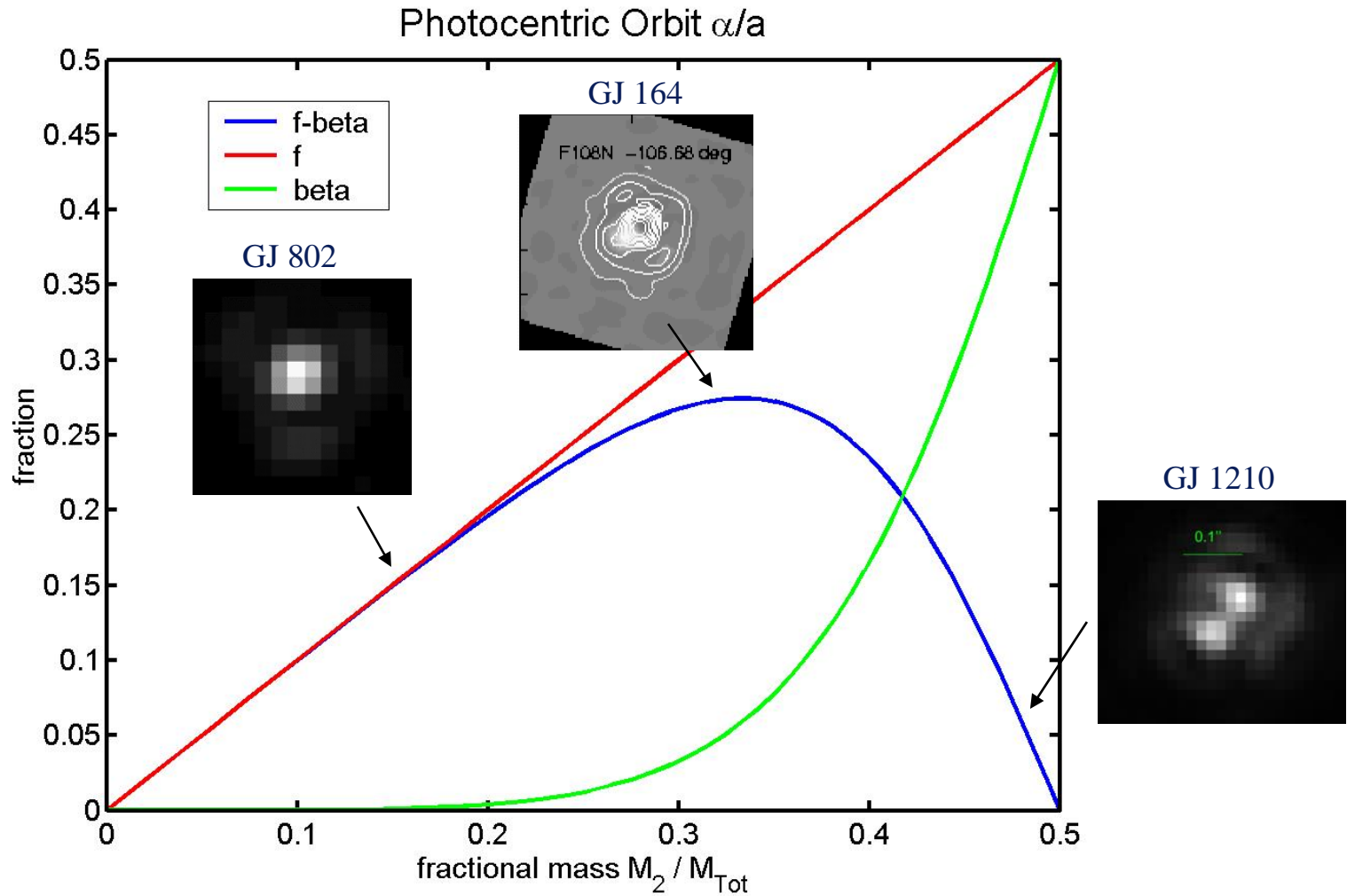
$$\alpha / a = \text{ratio of photocentric to Keplerian orbit} = f - \beta$$



Photocentric Motion vs. Fractional Mass



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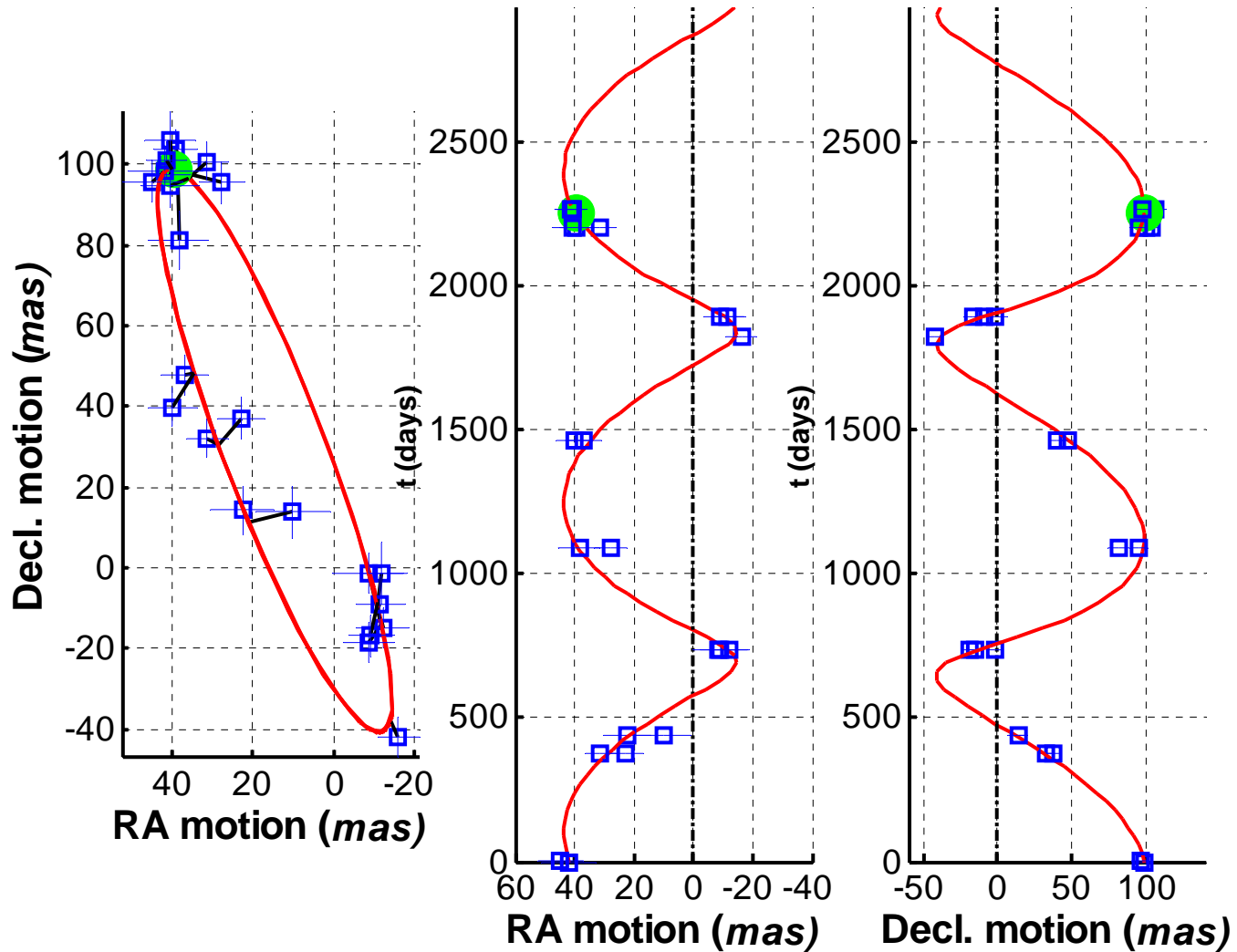


GJ 802

One possible orbit plotted with data, Keplerian frame



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GJ 802 Results



Table 1. GJ 802 Known Properties

RA (2000)^a	20 43 19.41
Dec (2000)^a	+55 20 52.0
V^b	14.69
J^c	9.563 ± 0.023
H^c	9.058 ± 0.019
K^c	8.753 ± 0.013
Type	dM5e
Parallax^d (<i>mas</i>)	63 ± 5.5
Proper Motion^e (<i>mas y⁻¹</i>)	1915 ± 13
Position Angle^e (deg)	27.6 ± 0.6

Table 2. STEPS Astrometric Measurements^a of GJ 802

Relative Parallax (<i>mas</i>)	61 ± 2
Proper Motion (<i>mas y⁻¹</i>)	1933 ± 1
Position Angle (deg)	27.0 ± 0.1
Period (y)	3.14 ± 0.03
Total Mass (M_{\odot})	0.215 ± 0.045
Semi-Major Axis (AU)	1.28 ± 0.10
Eccentricity, e	0.56 ± 0.30
Inclination (deg)	80.5 ± 1.5
Lon. Asc. Node^b (deg)	17.5 ± 3.5
Primary Mass, M_{pri} (M_{\odot})	0.160 ± 0.03
Secondary Mass, M_{sec} (M_{\odot})	0.057 ± 0.021

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- A paper is coming out in ApJ claiming to make the most precise mass measurement of a Brown Dwarf.
- It is largely based on estimates of our published GJ802b plot, shown below.
 - The authors measured the points in the published plot, estimated the observation date, then tried to reconstruct the original data by adding in the estimated parallax and proper motion.
 - They combined this data with their own imaging data and for good measure they threw out their original detection data because it had been incorrectly processed.

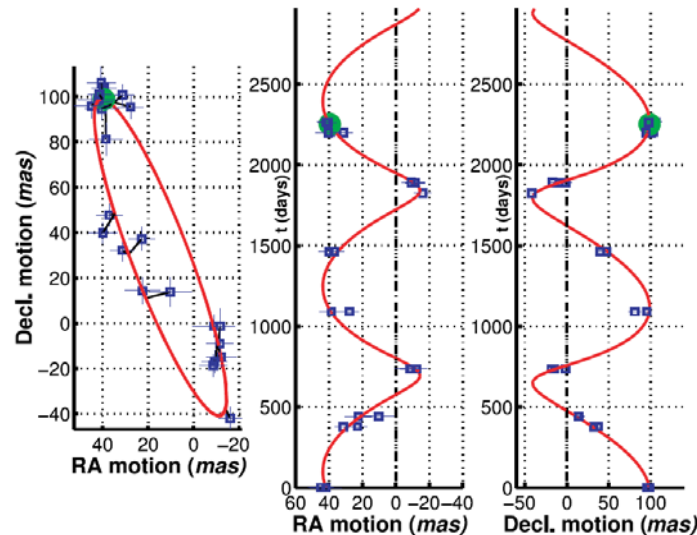


FIG. 1.—STEPS data (points) are superposed on a model of the Keplerian circular orbit (solid red lines). The right ascension and declination dimensions vs. time are shown separately. The 1σ error bars on the points are our photocentric measurement errors multiplied by the ratio of the Keplerian to the photocentric orbit. The position of the AO observation is also shown (green filled circle).

- **WE DO NOT ENDORSE THEIR RESULT.**

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- **Continued observation at Palomar 200 in.**
 - We are in our 10th year, and have the sensitivity to detect Jupiter mass objects in 10-yr orbits around several stars.
- **Explore Mount Wilson 100 in. for higher temporal sampling**
 - R&TD funding ~ 10-12 nights
- **RV and imaging collaborations**
 - Flux ratios for MLR
 - Velocities for improved orbits
- **Astrometric collaborations**
 - Overlapping target lists to confirm discoveries, improve orbital fits, help distinguish systematic errors from real motions.
- **Investigate new HAWAII-2RG detectors: higher dynamic range possible**
- **GIMLI: Proposed moderate cost space mission**
 - J-band, meter-class aperture, 50 μ as astrometry and coronagraphy (10^{-6} contrast).
 - 1000 astrometric targets, sensitivity to $0.1 M_J$
 - See accompanying talk by Steve Pravdo



- **“Masses of Astrometrically Discovered and Imaged Binaries: G78-28AB and GJ 231.1BC”** Pravdo, Shaklan, et al., ApJ, 649, 398 (2006)
- **“Astrometric Discovery of GJ802b: In the Brown Dwarf Oasis?”** Pravdo, Shaklan, Lloyd, ApJ, 630, 528 (2005)
- **“Discovering M-dwarf Companions with STEPS,”** Pravdo, Shaklan, Lloyd, Benedict, ASP Conf. Series, Astrometry in the Age of the Next Generation of Large Telescopes (Flagstaff, 2005).
- **“Astrometric Discovery of GJ164B,”** Pravdo, Shaklan, Henry, Benedict, ApJ 617, 1323-1329 (2004).
- **“Stellar Planet Survey,”** Pravdo & Shaklan, Scientific Frontiers in Research on Extrasolar Planets, ASP Conference Series, Vol 294, 107-110 (2003).
- **“Astrometric Detection of Extrasolar Planets: Results of a Feasibility Study with the Palomar 5 Meter Telescope,”** Pravdo & ApJ 465, 264-Astrophysical Journal v.465, p.264-277 (1996)
- **“High-precision measurement of pixel positions in a charge-coupled device,”** Shaklan, Pravdo, Sharmon, Appl. Opt. 34, 6672-6681 (1995).